(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
24 December 2003 (24.12.2003)

PCT

(10) International Publication Number
WO 03/107299 A2

(51) International Patent Classification⁷: G08G

(21) International Application Number: PCT/US03/09508

(22) International Filing Date: 31 March 2003 (31.03.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/368,539 1 April 2002 (01.04.2002) US
10/315,114 10 December 2002 (10.12.2002) US

(71) Applicant (*for all designated States except US*): **RYAN INTERNATIONAL CORPORATION** [US/US]; 4800 Evanswood Drive, Columbus, OH 43229 (US).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): **BRODEGARD, William, C.** [US/US]; 2138 Berlin Station Rd., Delaware, OH 43015 (US). **RYAN, Dean, E.** [US/US]; 7940 Harriott Road, Dublin, OH 43017 (US).

(74) Agent: **MONTGOMERY, Keith, C.**; Connolly, Bove, Lodge & Hutz, LLP, 1990 M Street, N.W., Suite 800, Washington, DC 20036-3425 (US).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

WO 03/107299 A2

(54) Title: METHOD AND DEVICE FOR PROTECTION AGAINST RUNWAY INCURSIONS

(57) Abstract: A runway incursion device carried on an aircraft provides a warning of existing or likely runway incursion. The device determines present and future positions of the aircraft and determines whether the aircraft has committed or will commit a runway incursion. The device can utilize inputs from global positioning system to determine aircraft position and other aircraft motion data. The device can also utilize data from an airport mapping database to determine what parts of the airport are protected runway areas. If the device determines that a runway incursion has occurred or is likely to occur, a warning can be generated to alert the pilot.

METHOD AND DEVICE FOR PROTECTION AGAINST RUNWAY INCURSIONS

CROSS REFERENCE TO RELATED APPLICATIONS

[01] This application claims priority to United States Provisional Application Serial Number 60/368,539 filed April 1, 2002, which is hereby incorporated by reference in its entirety.

BACKGROUND

TECHNICAL FIELD

[02] The present invention relates generally to instruments that warn against or prevent runway incursions.

RELATED ART

[03] A runway incursion occurs whenever an airplane, vehicle, person, or other object on the ground enters an area of an airport in which it creates a collision hazard with another airplane that is taking off or landing at an airport. Traditionally, pilots have relied on visual aids such as airfield markings (e.g., painted center lines), signs, and lighting, used in conjunction with a chart of the airport in order to navigate the airfield surface. Pilots may also receive via radio a taxi route from air traffic control (ATC) to follow while on the airfield surface. The pilot must then memorize or record the taxi route, re-state it to the controller for confirmation, and then follow airfield markings while avoiding other surface traffic and obstructions. Meanwhile, the ground controller must remember the taxi routes given to all aircraft and monitor aircraft movements so that no aircraft is directed into a potential conflict. Aircraft flight crews navigate on the airport surface primarily by sight to

ascertain positions along their assigned taxi route. When in doubt of their location, the ground controller (if one is available) can be queried by radio.

[04] Traditional procedures may be sufficient if airport surfaces are not congested and visibility is good. However, as airport traffic volume has increased, airport surfaces have become increasingly congested even in clear weather. Airport congestion has led to a need to perform more operations in low visibility and at night. Further, the increasing demand for higher takeoff and landing capacity has led to increasingly complex airport layouts. These factors, along with the additional factors of airport construction, misunderstood clearances, and tight operational schedules have increased the number of runway incursions. Traditional procedures and technologies are insufficient to account for these factors.

[05] From 1997 to 2000, 1369 runway incursions were reported at more than 450 towered airports in the United States. The Federal Aviation Administration (FAA) determined that 60% of the reported incursions were the result of pilot error. If it is assumed that the pilot errors were inadvertent, then 60% of the reported runway incursions could have been avoided if the pilots had maintained adequate situational awareness, during their taxi, of own-ship and taxi route position relative to the airport layout. The National Transportation Safety Board (NTSB) made recommendations for reducing runway incursions including a recommendation that the FAA require all airports with scheduled passenger service to utilize a ground movement safety system to prevent runway incursions. In response to these recommendations, the FAA implemented a runway incursion mitigation strategy that includes: publication of pilot guidance material, improved signage and markings so that ATC delineated routes are easier to follow, and installing improved lighting.

[06] The FAA has also initiated a long-term strategy for mitigating runway incursion focusing on airport infrastructure upgrades and improving the ATC surface surveillance picture.

[07] The traditional procedures and proposed improvements do not, however, provide the aircraft crew sufficient information regarding aircraft location and airport layout in order to most safely navigate the airport.

SUMMARY

[08] According to a first embodiment, an aircraft carried device for providing incursion information comprises a processor that receives inputs of aircraft data defining, for example, a position, velocity and acceleration of the aircraft, and that determines when the aircraft commits an incursion of a runway (or, more generally, a "protected area") of an airport or when an incursion is likely. The device may also include at least one alert device coupled to the processor, wherein the at least one alert device is responsive to the processor and generates a warning condition when the aircraft commits an incursion or is likely to commit an incursion of a protected area.

[09] According to the first embodiment, the aircraft pilot or other operator is provided with information to validate or possibly override a controller's order, and the pilot can avoid runway incursions at both towered and non-towered airports.

[10] According to a second embodiment, a runway incursion monitoring method comprises receiving aircraft data aboard an aircraft defining at least the aircraft's position, receiving airport data aboard the aircraft defining protected areas of an airport, determining whether the aircraft commits an incursion or is likely to commit an incursion of a protected area, and generating a warning condition if the aircraft commits an incursion or if the aircraft is likely to commit an incursion.

[11] According to the second embodiment, the pilot is warned when a runway incursion has occurred or is likely to occur. The pilot may then take corrective action to avoid a collision or other disruption of airport operations.

BRIEF DESCRIPTION OF THE FIGURES

[12] The foregoing and other features and advantages of the invention will be apparent from the following, more particular description of a preferred embodiment of the invention, as illustrated in the accompanying drawings:

[13] FIG. 1 illustrates a segment of an airport.

[14] FIG. 2 illustrates a first embodiment of a runway incursion monitor.

[15] FIG. 3 illustrates a second embodiment of a runway incursion monitor.

[16] FIG. 4 illustrates a third embodiment of a runway incursion monitor.

[17] FIG. 5 illustrates a method for monitoring runway incursions.

[18] FIG. 6 illustrates an alternative method for monitoring runway incursions.

[19] FIG. 7 illustrates a method for operating an runway incursion device.

DETAILED DESCRIPTION

[20] FIG. 1 illustrates a segment of an airport 100. Airport layouts may vary substantially, and FIG. 1 is therefore merely an example of an airport layout to explain the operation of the runway incursion monitor embodiments disclosed herein. The airport segment 100 comprises a runway 10, a first taxiway 15, a second taxiway 55, and a plurality of hold short lines 80a, 80b, 80c, and 80d.

[21] In FIG. 1, a protected runway exclusion area 20 (the shaded area in FIG. 1), or simply "protected area" 20, is bounded by a boundary 22. The boundary 22 generally comprises the hold short lines 80a, 80b, 80c, 80d, and the outer boundaries of the runway 10 that are indicated by bold outline. The protected area 20 can be defined as an area that is reserved to an aircraft that is either taking off or preparing to take off, or landing on the runway 20. In FIG. 1, an aircraft 90 is taking off, and an aircraft 92 is taxiing on the second taxiway 55. According to one aspect of the runway incursion monitor embodiments disclosed herein, an aircraft having a runway incursion monitor can avoid inadvertently or improperly entering the protected area 20. For example, the pilot of the aircraft 92 having a runway incursion monitor could be warned against entering the protected area 20 during taxiing.

[22] The boundary 22 may alternatively comprise "extended" hold short lines 81a, 81b, 81c, and 81d. Extending the boundary 22 of the protected area 20 provides a greater safety margin to the pilot of the aircraft 92. Any portion of the boundary 22 may be extended in this way. The boundary 22 may be extended outward an arbitrary distance, according to the desired increase in safety.

[23] FIG. 2 illustrates a first embodiment of a runway incursion monitor 200. The runway incursion monitor 200 functions to insure that an aircraft 92 (see FIG. 1) carrying an

incursion monitor does not cross the boundary 22 of the protected area 20 without advance warning to the pilot, or, to warn the pilot when her aircraft has already entered the protected area. Intrusions into, or "incursions" of the protected areas of the airport are thereby avoided.

[24] The runway incursion monitor 200 comprises a data processor 220 coupled to a source 230 of position data. The source 230 of position data can be, for example, a global positioning system (GPS) mounted on the aircraft. An airport mapping database (AMDB) 210 is also coupled to the data processor 220 and includes airport data descriptive of the airport. The AMDB 210 may include, for example, a digital description of some or all of the airport's surface operating areas for aircraft, including, for example, areas such as ramps, taxiways, and runways, and hold short boundaries. One embodiment of an AMDB may comprise a CD-ROM having a description of airport geography. The AMDB 210 can be mounted on the aircraft and coupled to the data processor 220. Alternatively, the AMDB 210 could be a database formed by data describing the airport geography, broadcasted to the aircraft from the airport ATC. The data processor 220 may be coupled to alert devices such as, for example, an audio indicator 240 and a visual indicator 260. The audio indicator 240 and the visual indicator 260 may emit audible and visual warnings, respectively, when an aircraft is likely to or has crossed a hold short boundary, or any other part of the boundary of a protected area.

[25] The audio indicator 240 and the visual indicator 260 may also emit warnings or convey other information under other circumstances. For example, the visual indicator 260 can comprise one or more colored lights that may be illuminated to reflect different messages, such as yellow for "caution." The yellow caution light may, for example, be used to indicate that a runway incursion is likely to occur in the future. A red light may indicate a runway incursion has already occurred. A green light may indicate that there is no present likelihood of a runway incursion.

[26] The data processor 220 may also be coupled to an input device 280. The input device 280 allows the pilot or other device operator to utilize additional functions of the runway incursion monitor 200. The additional functions are described in detail below. The

input device 280 can comprise, for example, an input keypad, a keyboard, or one or more labeled buttons for use by the operator.

[27] The runway incursion monitor 200 receives aircraft position data from the source 230 of position data, and airport surface operating area data from the airport mapping database AMDB 210. Referring back to FIG. 1, the data processor 220 can continually or intermittently compare the present position of the aircraft with the protected area 20 of the airport 100 defined by the border 22. Referring to FIGS. 1 and 2, the runway incursion monitor 200 registers a "warning condition" for the aircraft when the present position of the aircraft 92 makes a transition from the unprotected to the protected side of one of the hold short lines 80a-d, thereby violating the protected area 20. The warning condition may include a warning from the indicators 240, 260. The warning can be, for example, an audio warning from the audio indicator 240, a visual warning from the visual indicator 260, or a combination of audio and visual warnings.

[28] The transition of an aircraft's position from the protected to the unprotected side of a hold short boundary might also occur. This transfer typically occurs shortly after an aircraft lands at an airport and exits the runway. For simplicity, however, the transition to be protected against may be limited to the transition from an unprotected taxiway to a protected runway.

[29] The runway incursion monitor 200 may also provide an advance warning of an expected or likely incursion by the aircraft into a protected area. The warning condition is registered and a warning is provided before the aircraft actually violates the protected area. One way for the runway incursion monitor 200 to provide advance warning is to use data such as aircraft data and airport descriptive data to predict when a runway incursion is likely to occur.

[30] In one application, the data processor 220 can receive or calculate aircraft data, such as aircraft position and velocity, and predict the aircraft's position at some future time t. The prediction may be based on the assumption that the aircraft velocity will be maintained constant or relatively constant. Aircraft data such as acceleration may also be a factor in a more sophisticated application. The airport characteristic data can be provided by the

AMDB 210. The data processor 220 will generate a warning condition, preferably activating one or more of the warning indicators 240, 260, if the predicted or expected aircraft position involves a transition from an unprotected to a protected side of a hold short line (i.e., an incursion of a protected area). The warning condition can be registered and an audio/visual warning generated at the time the aircraft is expected to come within a preselected distance of a boundary, or at a predetermined time before an expected incursion of a protected area.

[31] According to the above embodiment, the runway incursion monitor 200 alerts a pilot of an expected or existing incursion of a protected area of an airport.

[32] The audio indicator 240 may be, for example, a speaker in the cockpit of the aircraft, or an audio signal source coupled to headphones worn by the pilot. The visual indicator 260 can be, for example, a display screen, or one or more lights. Other alert devices may be used in addition to or in lieu of these devices. The pilot or other operator may deactivate one or more of the alert devices 240, 260 by acknowledging the warning condition using the input device 280.

[33] FIG. 3 illustrates a second embodiment of a runway incursion monitor 300. The runway incursion monitor 300 receives the aircraft data of position, velocity, and acceleration to more precisely predict the motion of an aircraft as a function of time. One equation which can be used to describe position as a function of time is:

$$(1) \qquad P(t) = P(0) + v \cdot t + \tfrac{1}{2} \cdot a \cdot t^2$$

where:

$P(t)$ is the expected aircraft location at future time t,

$P(0)$ is the current aircraft location at time $t = 0$,

v = aircraft velocity at time $t = 0$, and

a = aircraft acceleration.

[34] The runway incursion monitor 300 comprises a data processor 220 coupled to the airport mapping database 210, an audio indicator 240, a visual indicator 260, and an input device 280. The data processor 220 is also coupled to sources of aircraft data, such as a source 230 of position data, a source 305 of linear velocity data, a source 310 of linear acceleration data, a source 320 of heading data, source 340 of angular velocity data, and a source 350 of angular acceleration data. The linear velocity data, linear acceleration data, angular velocity data, and angular acceleration data can be derived from the position data and the heading data, or provided as individual inputs to the data processor 220. The heading data and linear velocity data can be calculated from the position data, or provided as individual inputs to the data processor 220. The operation of the monitor 300 is discussed in further detail below with reference to the method illustrated by FIG. 5.

[35] FIG. 4 illustrates an embodiment of a runway incursion monitor 400 having additional devices that provide data to the data processor 220. The runway incursion monitor 400 includes a data processor 220, an AMDB 210, an audio indicator 240, a visual indicator 260 and an input device 280, as are generally described with reference to the embodiments illustrated in FIGS. 2 and 3. Additional devices include an air traffic control (ATC) data link 410, an airspeed sensor 420, a moving map display 430, a weight-on-wheels (WOW) sensor 435, and a laptop computer 460.

[36] The additional devices included in the runway incursion monitor 400 allow a more detailed and accurate calculation of when there is a likely or existing incursion of a protected area of an airport by an aircraft carrying the runway incursion monitor 400. The ATC data link 410 provides data that can improve the accuracy of the position fix of the runway incursion monitor 400. The ATC data link 410 can also be used to allow input of high speed data and the transmission of information to other monitors and to ATC personnel. The airspeed sensor 420 indicates the airspeed of the aircraft. The moving map 430 displays runways likely to be affected by a present or likely incursion. The moving map 430 receives data from the data processor 220, and when an incursion warning is activated, the affected runway(s) are highlighted and/or displayed prominently on a moving map. The WOW sensor 435 indicates whether there is weight supported by the aircraft's wheels. The WOW

data is used to determine when the aircraft is airborne. The laptop computer 460 may be used by the pilot to, for example, input taxi routes.

[37] The runway incursion monitor 400 can utilize the inputs of latitude, longitude, altitude, velocity, acceleration as discussed with reference to FIGS. 3 and 4. The source of these data is illustrated as a source 470 of position data.

[38] The operation of the runway incursion monitor 400 is discussed in further detail below with reference to FIG. 5.

[39] FIG. 5 illustrates a method for monitoring runway incursions. The method illustrated in FIG. 5 can be used to determine whether an aircraft carrying a runway incursion monitor has committed an incursion of a protected area or will likely commit an incursion. The method can be performed using the runway aircraft incursion monitors 200, 300 or 400 described above.

[40] In step 510, the processor 220 determines the present position of the aircraft on which the monitor is carried using aircraft position data. In step 515, the motion parameters of the aircraft are determined. The motion parameters may include aircraft data such as the aircraft's linear velocity, linear acceleration, heading, angular velocity and angular acceleration, depending upon the inputs available to or requested by the data processor 220.

[41] Once current motion parameters are determined at step 515, step 520 determines whether the aircraft is airborne. This determination is made according to the sensor inputs available to the processor 220. For example, referring to FIG. 4, the WOW sensor 435 output can be used to determine whether the aircraft is airborne. Other devices and methods useful to determine whether the aircraft is airborne include, for example, a switch operable by the pilot, a "landing gear down" sensor, and a comparison of the aircraft altitude with the altitude of the terrain at the aircraft's position. The airspeed or groundspeed of the aircraft can also be used to determine whether the aircraft is airborne. If the aircraft is traveling at a speed above a minimum value, such as 45 knots, it is likely that the aircraft is either airborne or in a takeoff condition, because aircraft seldom taxi at a speed of 45 knots or greater.

[42] If it is determined at step 520 that the aircraft is airborne, any current warning conditions are cleared in step 530. In general, if the aircraft is airborne, then runway incursion prevention is not required.

[43] If it is determined in step 520 that the aircraft is not airborne, then step 540 is performed to determine if the aircraft is accelerating towards takeoff. There are a variety of ways to implement this function. For example, referring to FIG. 3, if the aircraft's present position locates it on a runway and the aircraft's acceleration is positive, then a conclusion could be drawn that the aircraft is accelerating towards takeoff. A positive acceleration can be determined in the data processor 220 according to data from the source 310 of linear acceleration data. If the processor 220 determines that the aircraft is accelerating toward takeoff, existing warning conditions are cleared in step 530.

[44] If the processor 220 determines that the aircraft is not accelerating towards takeoff, then step 550 is performed to determine if there is a current warning condition. A current warning condition may exist if an incursion or a likely incursion was detected in a previous execution of the runway incursion method. If there is no current warning condition, step 560 is performed to calculate an expected future position of the aircraft. The future position may be calculated according to equation (1) recited above, for example. A more sophisticated calculation can incorporate, for example, angular acceleration values. The future position of the aircraft is calculated in order to determine whether the aircraft is in danger of violating a protected area.

[45] The future position of the aircraft may be calculated to predict the aircraft's expected position at a selected future time t. The time t can be selected to provide sufficient response time to the pilot before the aircraft actually crosses a boundary of a protected area. For example, a future time t of 20 seconds would provide a pilot sufficient time to alter the aircraft's path if it is in danger of committing an incursion into a protected area. A shorter time can be used to avoid unnecessary warnings.

[46] The future position at time t may be calculated based on some or all of the known aircraft data, including the motion parameters of linear velocity, angular velocity, linear acceleration, angular acceleration, and heading, and the present position of the aircraft.

[47] Having calculated the future position, step 570 then determines if the future position would result in an incursion of a protected area. In defining boundaries of a protected area, the hold short lines can be "extended" outward an arbitrary amount to increase the margin of safety. The protected area may thereby be extended as shown in FIG. 1, where hold short lines 81a-81d provide an extended protected area 20. In one application, each of the hold short lines, or other boundaries of a protected area can be extended 10-20 feet outward. The additional distance increases the time available for the pilot to react to a likely incursion of a protected area. Alternatively, the processor 220 can determine whether the aircraft comes within a minimum distance of the boundary of the protected area. If so, the processor can conclude that an incursion is likely. The distance can be dependent upon the velocity of the aircraft, so that sufficient time is allotted to warn the pilot of a fast-moving aircraft.

[48] In step 570, if an incursion is likely to occur at future time t, then a warning condition is generated in step 580. The warning condition can include a warning signal that can be an audio signal, a visual signal, a combination thereof, or an alternative signal designed to warn the pilot of a possible incursion of a protected area. If no incursion is determined to be likely at time t, the method returns to step 530 where warning conditions are cleared.

[49] Referring again to step 550, if there is a current warning condition, the processor 220 determines whether the aircraft is inside a protected area in step 590. This condition can be determined by comparing the present aircraft position with airport data from the AMDB 210. If at step 590 it is determined that the aircraft is currently within a protected area, then step 592 is performed to determine if the pilot has acknowledged the current warning condition determined in step 550. The pilot can acknowledge a current warning condition by, for example, inputting data at the input device 280 (see FIG. 2). If the pilot has not acknowledged the current warning condition, the warning condition is maintained as "active" in step 598. The method then returns to step 510. If the warning condition is active, the warning indicators 240, 260 can continue to produce warning signals. The pilot may, at her option, mute an audio warning signal, while maintaining a visual warning signal.

[50] If the pilot has acknowledged a warning condition, the warning condition is cleared in step 596. The future position of the aircraft is then calculated in step 560 and the method proceeds as described above.

[51] Returning to step 590, if the aircraft is not determined to be in a protected area, the warning condition determined in step 550 is cleared in step 596. The future position of the aircraft is then calculated in step 560 and the method proceeds as described above.

[52] In addition to the functions described above, the input device 280 allows several additional functions to be performed by the runway incursion monitors described above. For example, when the aircraft turns and stops at a runway, the data processor 220 recognizes the aircraft is holding short. At this time, the visual indicator 260 may give a status indication, such as, for example, an illuminated yellow status light. An audible announcement of status may also accompany the visual indication. An input at the input device 280 can be used to elicit a current location or status of the aircraft such as: "HOLDING SHORT, RUNWAY 9-27, INTERSECTION TAXIWAY BRAVO. RUNWAY 9, RIGHT TURN, 5000 FEET REMAINING. RUNWAY 27, LEFT TURN, TWO THOUSAND FIVE HUNDRED FEET REMAINING." The airport mapping database 210 may contain the digital data necessary for the data processor 220 to compare the aircraft's current position to the airport geography, including runways and other protected areas of the airport. The AMDB can also extract a verbal text string indicating the status of the aircraft, for use by the flight crew.

[53] The runway incursion monitor can also indicate a landing status for an aircraft. For example, when an embodiment of a runway incursion monitor is in use aboard an aircraft that is preparing to land, the runway incursion monitor can issue a reminder to indicate that the aircraft is cleared to land, and may allow verification that the aircraft is aligned with the correct runway. For example, when in the air, on final approach, the pilot can input a query at the input device 280 to determine whether ATC has granted clearance to land. The visual indicator 260 can respond with a positive (e.g., a green light) or a negative (e.g., a red light) indication as to landing clearance. Audio indications may also be generated. The query by the pilot can be the press of a button, or a more detailed input at, for example, a keyboard.

[54] A second input at the input device 280 can be entered after entering final approach to task the runway incursion monitor to announce the assigned runway. The assigned runway can be displayed on the visual indicator 260, or announced over the audio indicator 240. The landing clearance and the announced runway should be the same. If not, corrective action can be taken before the flare.

[55] Using a specialized input device, such as a laptop computer keyboard 310, allows rapid input of an assigned taxi route. The data processor 220 can be set to alarm when the future position is greater than a predetermined distance from the assigned taxi route. In this embodiment the data processor 220 determines the distance between the taxi route and the future position and between the future position and the nearest protected boundary.

[56] FIG. 6 illustrates an alternative method for monitoring runway incursions. In step 610, the aircraft position is determined. In step 620, aircraft motion parameters such as velocity, acceleration, heading, angular velocity and angular acceleration are determined. In step 630, the data processor 220 compares the aircraft position with the airport data from the AMDB 210 to determine if the aircraft's present position is on a runway. If the aircraft is on a runway, the processor 220 assumes that an incursion has not occurred and that the pilot does not require a warning. The method then returns to step 610.

[57] Referring back to step 630, if the aircraft's present position is not on a runway, then step 640 determines if the aircraft is airborne. If the aircraft is not airborne, then a future predicted position is determined in step 650. The future position may be calculated by projecting the present position at a time t along the trajectory described by the simultaneous solution of linear and angular motion algorithms.

[58] In step 660, the predicted position and the present position of the aircraft are compared to the protected area 20 to determine if the predicted or the present position lie in a protected area 20. If yes, in step 670, the processor 220 determines whether it is physically possible for the aircraft to travel from its present position to its predicted position (if the present position is in a protected area a path is considered to exist). An arc drawn between the aircraft's present position and its predicted position at time t is the track that the aircraft will follow as it taxis. If a continuous surface approved for transit by aircraft does

not exist between the present position and the predicted position, the processor 220 assumes that the aircraft will not follow the predicted route and that the incursion from that predicted position will not occur. Therefore, a warning condition is not generated and the method returns to step 610.

[59] If a continuous path exists between the present position and the predicted position, step 680 determines if the aircraft is holding short awaiting permission to enter the runway. Since the aircraft is next to the boundary of the protected area when holding short (see FIG. 1), it is possible that the predicted position may be in the protected area. Warning the pilot of an impending runway incursion when holding short would be an erroneous warning, and could distract the pilot. Therefore, if the aircraft is holding short, the alert devices 240, 260 are not activated. Alternatively, the alert devices 240, 260 can give an indication that the aircraft is holding short. The status of holding short can be input, for example, by the pilot at the input device 280.

[60] If the aircraft is not holding short, a warning condition is generated in step 690. The warning condition can include activation of the audio indicator 240 and the video indicator 260. An audio warning could be in the format of: "CAUTION RUNWAY 09-27 AHEAD" wherein 09-27 is the runway number. The visual indicator 260 can display the foregoing message in flashing text, for example. Alternatively, a red lamp may be lighted in the view of the pilot. In addition, a moving map, such as the moving map 430 illustrated in FIG. 4, can display the affected runway, and the predicted incursion point.

[61] The input device 280 may be used to acknowledge the approach to the runway, such as when the processor 220 determines that an incursion is likely. If the pilot acknowledges the warning condition in step 695, the warning condition is cleared in step 697 and the method returns to step 610. If the pilot does not acknowledge the warning condition, the warnings from the devices 240, 260 may continue until the pilot acknowledges or corrects the condition.

[62] The input device 280 can include a "mute/position update" button. A method of enabling the mute and position update functions is discussed below with reference to FIG. 7.

[63] The runway incursion monitor embodiments discussed above may use position data from the source 230 of position data as the only external data source. The source 230 may be, for example, a GPS receiver on the aircraft that is in communication with the processor 220. Alternatively, an inertial navigation system could be included on the aircraft to provide position and motion data to the processor 220. If not using velocity and acceleration information, the data processor 220 prediction algorithms may be simplified by setting the predicted aircraft position at time *t* equal to the present aircraft position. Using only position data, the incursion monitor 200 may advantageously generate a warning condition when the aircraft reaches a predetermined distance from the protected area. In this case, referring to FIG. 5, step 560 can be replaced with a step in which the processor 220 determines a predetermined distance from a protected area. Step 570 would accordingly register a likely incursion if the aircraft is located within the predetermined distance of the protected area. Similarly, in FIG. 6, step 650 could be used to determine the predetermined distance from the protected area boundaries, and step 660 could register a likely incursion if the aircraft passed into the predetermined distance. Referring to FIG. 1, the extended hold short boundaries 81a-81d could be used to define the predetermined distance from the boundary 22.

[64] As a safety and reliability feature, the data processor 220 may routinely calculate the distance between the aircraft's present position and a protected area, in addition to calculating the predicted position of the aircraft. Therefore, if a failure in the runway incursion monitor were to disrupt the future position calculation, a backup function could warn the pilot that the aircraft is near the protected area. This function could be used if, for example, the runway incursion monitor had no access to velocity data.

[65] In the absence of velocity input or a way to determine the velocity, the data processor 220 may set aircraft velocity to zero and the future position prediction algorithms may set the future position equal to the present position. A warning condition will be generated (i.e., the processor 220 determines that an incursion is likely) if the aircraft moves within the preselected distance.

[66] In the embodiments discussed in this specification, the airport mapping database can include a complete description of the airport environment, including the location of all hold

short lines, for example. If particular sets of data are not provided to the airport mapping database, airport characteristics such as the location of hold short lines can be instead be determined and stored in the airport mapping database. For example, if the airport mapping database lacks data defining hold short lines, hold short lines can be determined using available airport database and FAA hold short line criteria. The "extended" hold short lines discussed above may also be determined and stored.

[67] FIG. 7 illustrates an example of a method of operating a runway incursion monitor embodiments discussed above. In this example, the input device 280 can be a single button.

[68] Step 710 illustrates a state where a warning condition exists and both audio and visual warnings are given by the audio indicator 240 and the visual indicator 260, respectively. The warning condition in this example can exist due to a likely incursion at a future time *t*, and the visual warning is a yellow light. If the aircraft had already crossed a boundary of a protected area, the light could be red. In step 720, a single press of the input button 280 mutes the audio indicator 240 (step 730), so that the pilot is not unnecessarily distracted.

[69] In step 740, the pilot presses the button 280 a second time and obtains a position update via the audio indicator 240. The position update may also include an alert as to the next airport feature in the path of the aircraft. The yellow warning light can remain on.

[70] In another example, the runway incursion monitor monitors aircraft status when the aircraft is stopped short. In this example, the input device 280 can be a single button.

[71] Referring to FIGS. 1 and 2, when the aircraft 92 turns and stops at a runway, the runway incursion device 200 may recognize that the aircraft 92 is holding short. The visual indicator 260 can display a yellow light, but no audible announcement is made. A double-press of the button can be used elicit a current location on the airport announcement such as: "HOLDING SHORT, RUNWAY 9-27, INTERSECTION TAXIWAY BRAVO. RUNWAY 9, RIGHT TURN, 5000 FEET REMAINING. RUNWAY 27, LEFT TURN, TWO THOUSAND FIVE HUNDRED FEET REMAINING."

[72] According to the above embodiments, pilots of aircraft having a runway incursion monitor have higher situational awareness in the airport environment. Higher situational

awareness reduces the number of runway incursions at towered airports, thereby increasing safety.

[73] The foregoing description of the specific embodiments will so fully reveal the general nature of the invention that others can, by applying knowledge within the skill of the art readily modify and/or adapt for various applications such specific embodiments, without undue experimentation, without departing from the general concept of the present invention. Therefore, such adaptations and modifications are intended to be within the meaning and range of equivalents of the disclosed embodiments, based on the teaching and guidance presented herein. It is to be understood that the phraseology or terminology herein is for the purpose of description and not of limitation, such that the terminology or phraseology of the present specification is to be interpreted by the skilled artisan in light of the teachings and guidance presented herein, in combination with the knowledge of one of ordinary skill in the art.

WHAT IS CLAIMED IS:

1. An aircraft carried device for providing incursion information, comprising:

a processor, wherein the processor receives inputs of aircraft data defining at least a position of the aircraft, and determines when the aircraft commits an incursion or when an incursion is likely of a protected area of an airport; and

at least one alert device coupled to the processor, wherein the at least one alert device is responsive to the processor and provides an indication of a warning condition when the aircraft commits an incursion or is likely to commit an incursion of a protected area.

2. The device of claim 1, wherein the at least one alert device comprises at least one of an audio and a visual alert device.

3. The device of claim 1, wherein the processor receives aircraft data comprising at least one of aircraft velocity data and acceleration data and uses the aircraft data to predict a future position of the aircraft.

4. The device of claim 3, wherein the processor generates a warning condition when the future position of the aircraft indicates a likely incursion of a protected area.

5. The device of claim 4, wherein the processor receives airport data and uses the airport data to determine protected areas of the airport.

6. The device of claim 4, wherein the airport data is data from an airport mapping database.

7. The device of claim 4, wherein the processor determines whether a path exists between the aircraft's position and the future position.

8. The device of claim 4, wherein the processor determines whether the aircraft is holding short.

9. The device of claim 4, wherein the processor determines that an incursion is likely when the aircraft comes within a predetermined distance of a protected area.

10. The device of claim 3, wherein the processor uses the acceleration data to determine whether the aircraft is accelerating toward takeoff.

11. The device of claim 3, wherein the aircraft data comprises aircraft angular acceleration data, linear acceleration data, angular velocity data, linear velocity data, and heading data.

12. The device of claim 1, comprising:

an input device coupled to the processor, the input device allowing an operator to acknowledge a warning condition.

13. The device of claim 1, comprising:

a moving display map display coupled to the processor, wherein the moving display map receives data from the data processor, and when a warning condition is generated affected runways are displayed on the moving map display.

14. The device of claim 1, further comprising an air traffic control data link coupled to the processor.

15. The device of claim 1, wherein the device uses the position data to provide a position update.

16. The device of claim 1, wherein the device uses the position data to provide a landing status.

17. An aircraft carried device for providing incursion information, comprising:

means for determining when the aircraft has committed or is likely to commit an incursion of a protected area of an airport; and

means for providing an indication of a warning condition.

18. The device of claim 17, comprising:

means for determining the aircraft's landing status.

19. The device of claim 17, comprising:

display means for displaying a map of the airport and for displaying protected areas of the airport.

20. The device of claim 17, comprising:

input means for allowing an operator to acknowledge a warning condition generated by the means for determining when the aircraft has committed or is likely to commit an incursion.

21. The device of claim 17, comprising:

means for determining when the aircraft is airborne.

22. The device of claim 17, comprising:

means for determining when the aircraft is accelerating towards takeoff.

23. The device of claim 17, comprising:

means for determining whether the aircraft is holding short.

24. The device of claim 17, wherein the means for determining when the aircraft has committed or is likely to commit an incursion comprises:

means for determining a protected area of an airport;

means for determining a position of the aircraft; and

means for determining whether the position of the aircraft is an incursion of a protected area.

25. The device of claim 24, comprising:

means for determining a path between the aircraft's position and a calculated future position of the aircraft.

26. The device of claim 24, comprising:

warning means for warning of an existing or likely incursion.

27. An incursion monitoring method, comprising:

receiving aircraft data aboard an aircraft defining at least the aircraft's position;

receiving airport data aboard the aircraft defining one or more protected areas of an airport;

determining whether the aircraft commits an incursion or is likely to commit an incursion of a protected area; and

generating a warning condition if the aircraft commits an incursion or if the aircraft is likely to commit an incursion.

28. The method of claim 27, wherein determining whether the aircraft commits an incursion comprises:

comparing the aircraft position to the protected areas to determine whether the aircraft has crossed a boundary of a protected area.

29. The method of claim 28, wherein generating a warning condition comprises:

activating at least one of an audio and a visual alert device.

30. The method of claim 28, wherein receiving aircraft data aboard the aircraft comprises:

receiving aircraft position data from a global positioning system receiver.

31. The method of claim 30, wherein receiving airport data aboard the aircraft comprises:

receiving data from an airport mapping database.

32. The method of claim 27, wherein determining whether the aircraft is likely to commit an incursion of a protected area comprises:

determining a future position of the aircraft; and

determining whether the future position is an incursion of a protected area.

33. The method of claim 32, wherein receiving aircraft data aboard an aircraft comprises:

receiving data indicating aircraft velocity and wherein determining a future position of the aircraft comprises using the velocity data to predict the future position of the aircraft.

34. The method of claim 32, wherein receiving aircraft data aboard an aircraft comprises:

determining whether a path exists between the aircraft's position and the future position.

35. The method of claim 27, wherein determining whether the aircraft is likely to commit an incursion of a protected area comprises:

determining when the aircraft comes within a predetermined distance of a protected area.

36. The method of claim 27, comprising:

determining whether the aircraft is airborne; and

clearing any warning conditions if the aircraft is airborne.

37. The method of claim 27, comprising:

determining whether the aircraft is accelerating towards takeoff; and

clearing any warning conditions if the aircraft is accelerating towards takeoff.

38. The method of claim 27, comprising:

determining whether there is a current warning condition;

determining whether an operator has acknowledged the warning condition; and

clearing the warning condition if the operator has acknowledged the warning condition.

39. The method of claim 27, wherein:

determining whether the aircraft commits an incursion comprises comparing the aircraft position to the protected areas to determine whether the aircraft has crossed a boundary of a protected area;

determining whether the aircraft is likely to commit an incursion of a protected area comprises determining a future position of the aircraft and determining whether the future position is an incursion of a protected area;

receiving airport data aboard the aircraft comprises receiving data from an airport mapping database; and

receiving aircraft data aboard an aircraft comprises receiving data indicating aircraft velocity.

40. The method of claim 39, comprising:

determining whether there is a current warning condition;

determining whether an operator has acknowledged the warning condition; and

clearing the warning condition if the operator has acknowledged the warning condition.

41. The method of claim 27, wherein generating a warning condition comprises:

activating at least one of an audio and a visual alert device.

42. The method of claim 27, comprising:

generating a status signal when the aircraft is holding short.

43. The method of claim 27, comprising:

generating a landing status signal when the aircraft is preparing to land.

44. The method of claim 27, comprising:

generating a position update; and

providing the position update to an operator by activating at least one of an audio and a visual alert device.

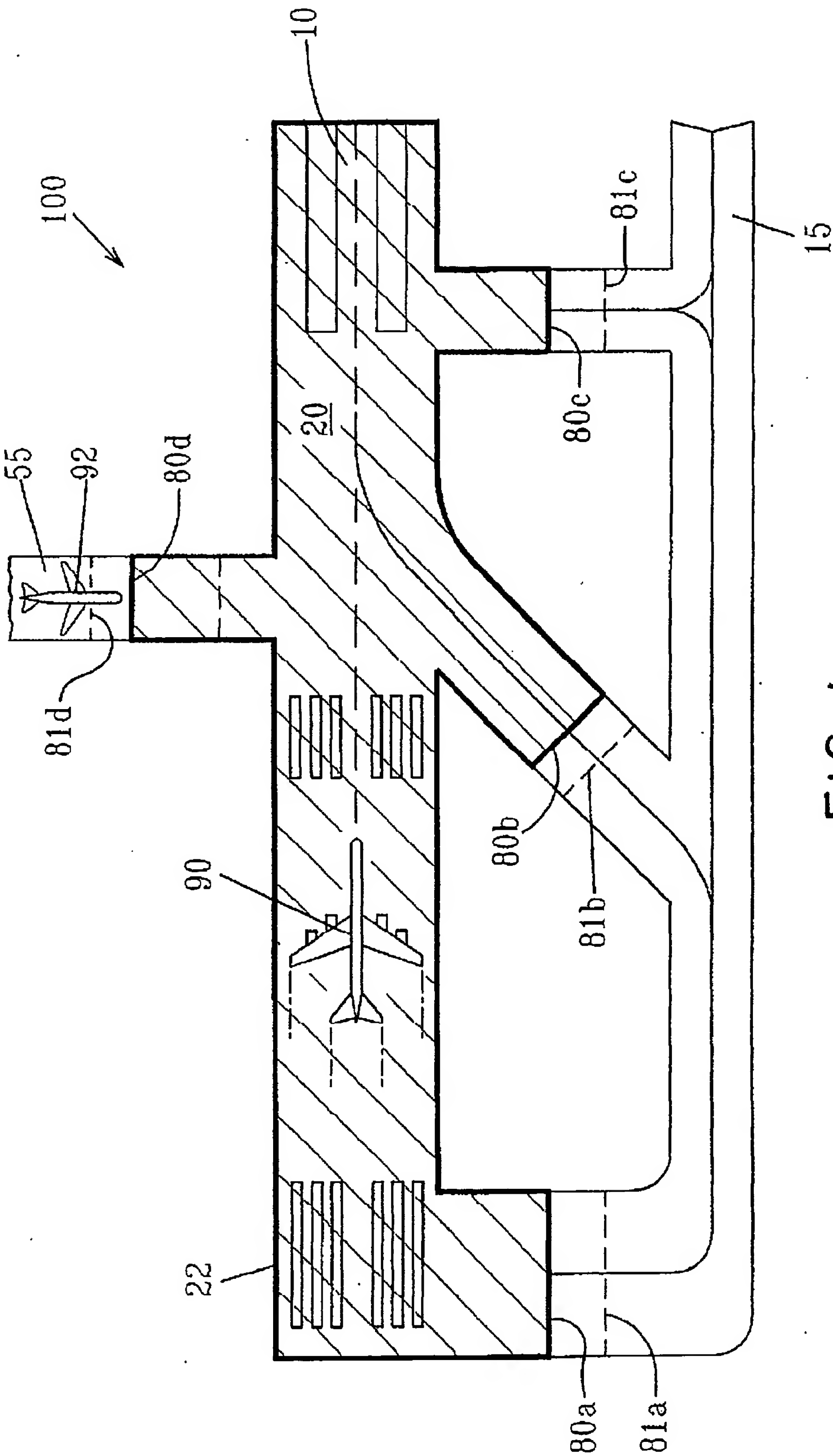

FIG. 1

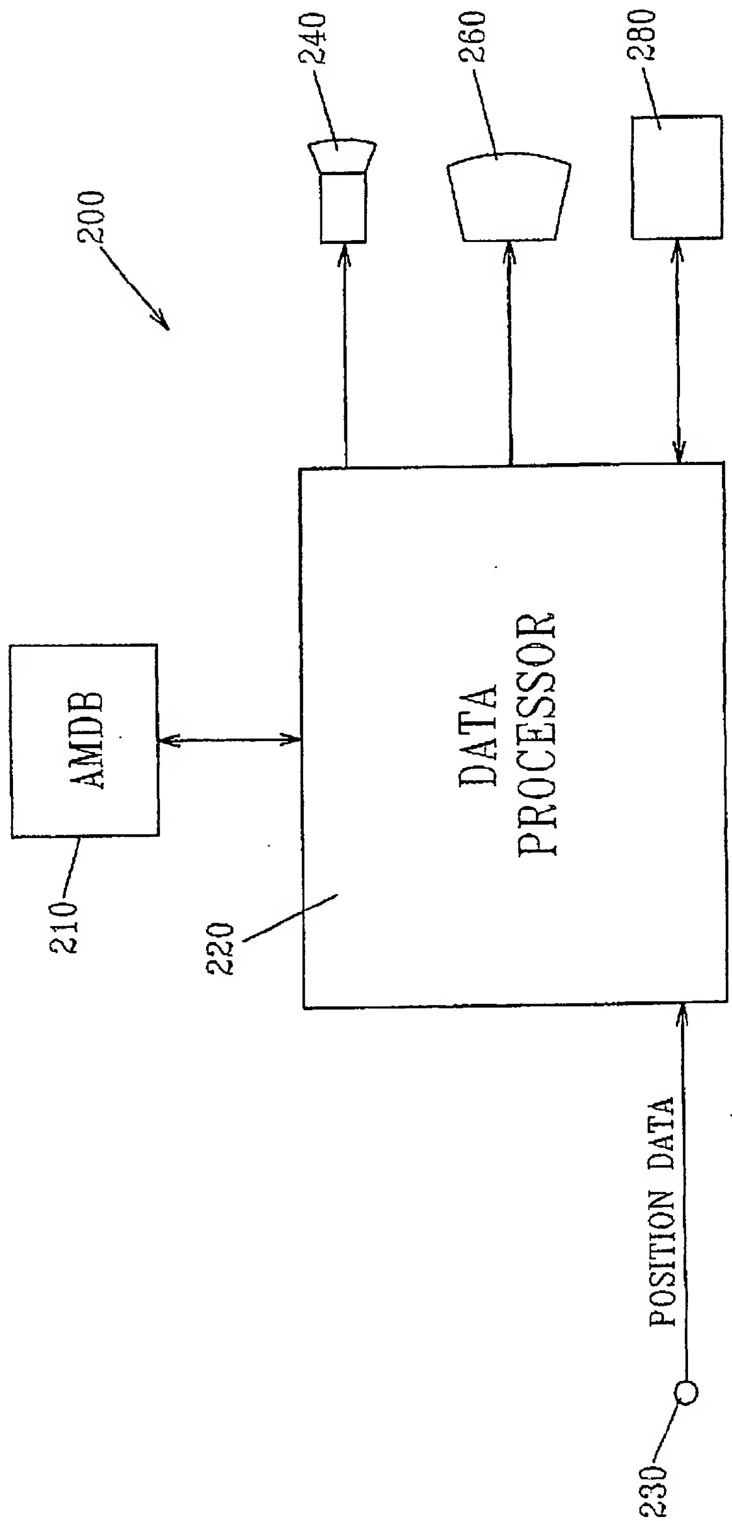
200
240
260
280
AMDB
210
DATA PROCESSOR
220
POSITION DATA
230

FIG. 2

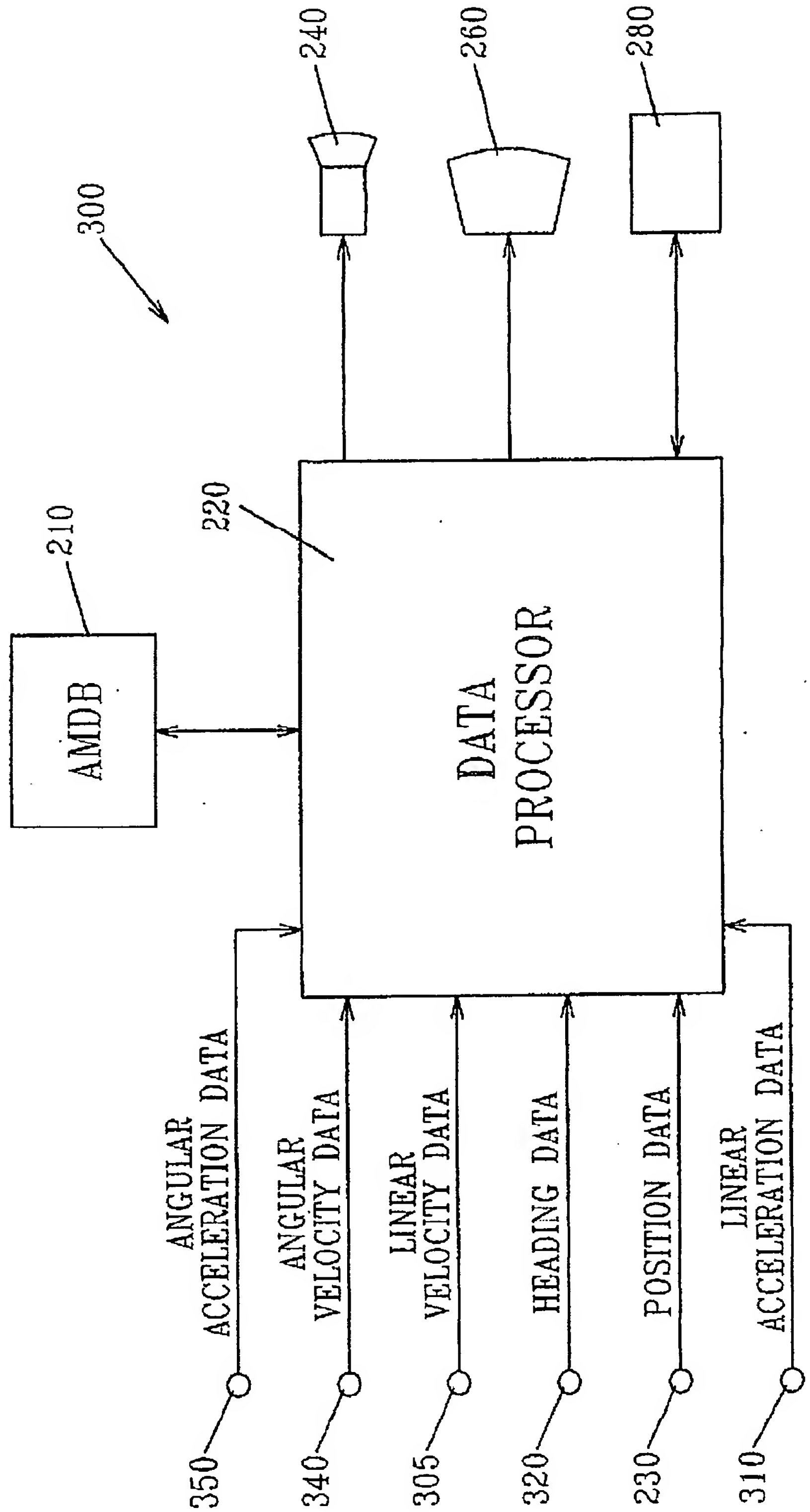
300
240
260
280
210
220
AMDB
DATA PROCESSOR
ANGULAR ACCELERATION DATA
ANGULAR VELOCITY DATA
LINEAR VELOCITY DATA
HEADING DATA
POSITION DATA
LINEAR ACCELERATION DATA
350
340
305
320
230
310

FIG. 3

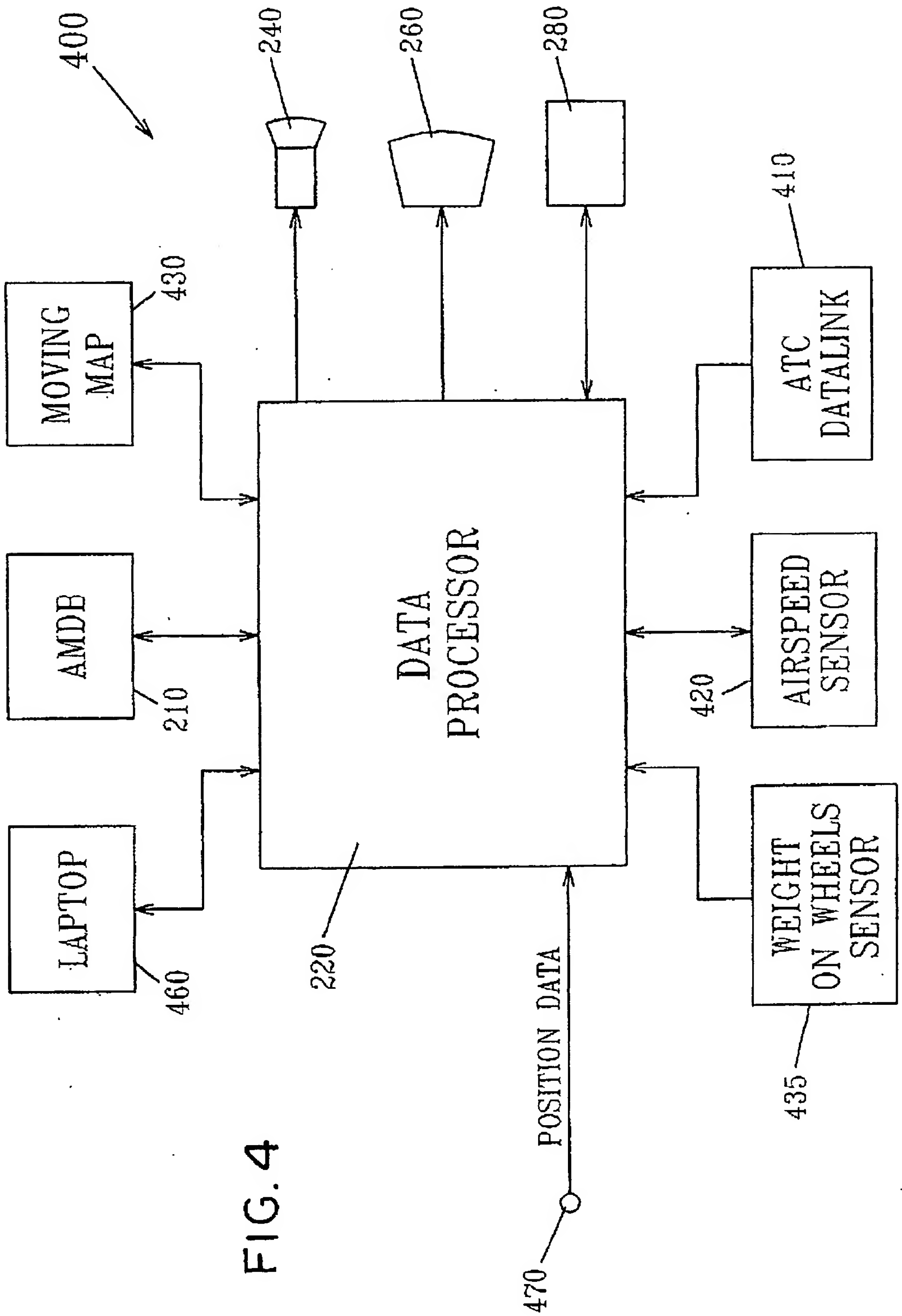
400
240
260
280
MOVING MAP
430
AMDB
210
LAPTOP
460
DATA PROCESSOR
220
ATC DATALINK
410
AIRSPEED SENSOR
420
WEIGHT ON WHEELS SENSOR
435
POSITION DATA
470

FIG. 4

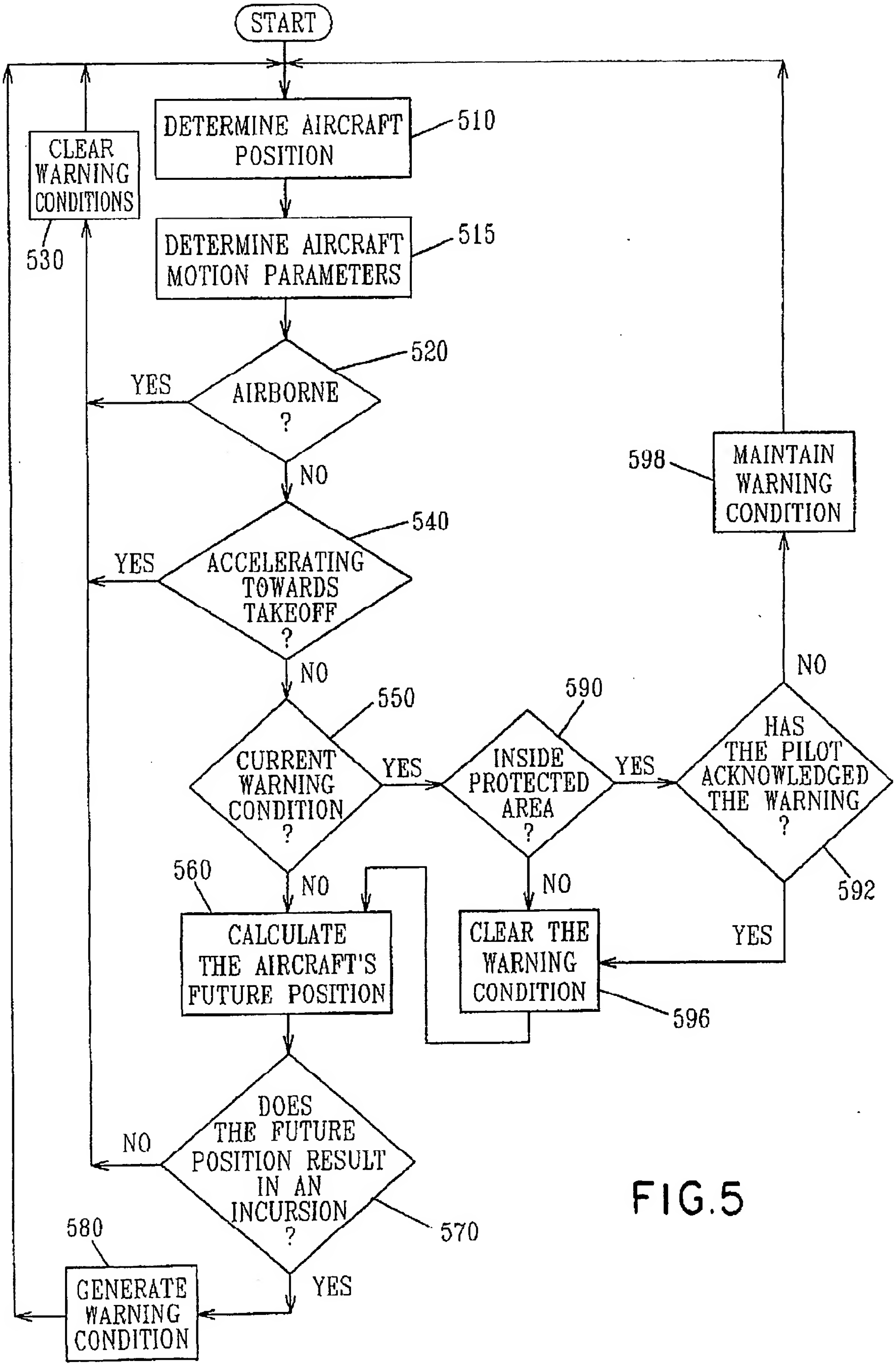
START
DETERMINE AIRCRAFT POSITION
510
DETERMINE AIRCRAFT MOTION PARAMETERS
515
CLEAR WARNING CONDITIONS
530
AIRBORNE ?
520
YES
NO
ACCELERATING TOWARDS TAKEOFF ?
540
YES
NO
CURRENT WARNING CONDITION ?
550
YES
NO
INSIDE PROTECTED AREA ?
590
YES
NO
HAS THE PILOT ACKNOWLEDGED THE WARNING ?
592
NO
YES
MAINTAIN WARNING CONDITION
598
CALCULATE THE AIRCRAFT'S FUTURE POSITION
560
CLEAR THE WARNING CONDITION
596
DOES THE FUTURE POSITION RESULT IN AN INCURSION ?
570
NO
YES
GENERATE WARNING CONDITION
580

FIG.5

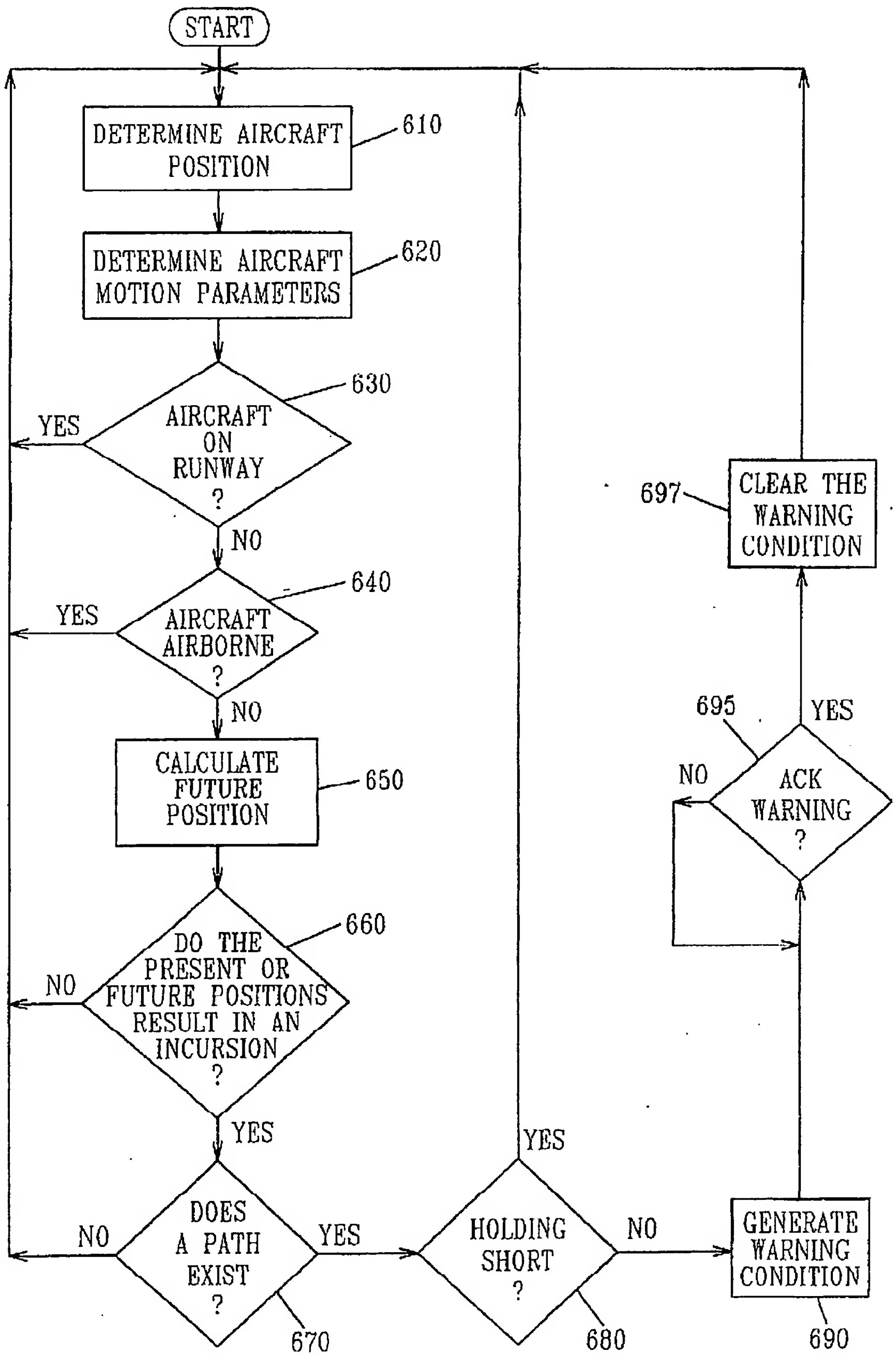
START
DETERMINE AIRCRAFT POSITION
610
DETERMINE AIRCRAFT MOTION PARAMETERS
620
AIRCRAFT ON RUNWAY ?
630
YES
NO
AIRCRAFT AIRBORNE ?
640
YES
NO
CALCULATE FUTURE POSITION
650
DO THE PRESENT OR FUTURE POSITIONS RESULT IN AN INCURSION ?
660
NO
YES
DOES A PATH EXIST ?
670
NO
YES
HOLDING SHORT ?
680
YES
NO
GENERATE WARNING CONDITION
690
ACK WARNING ?
695
NO
YES
CLEAR THE WARNING CONDITION
697

FIG. 6

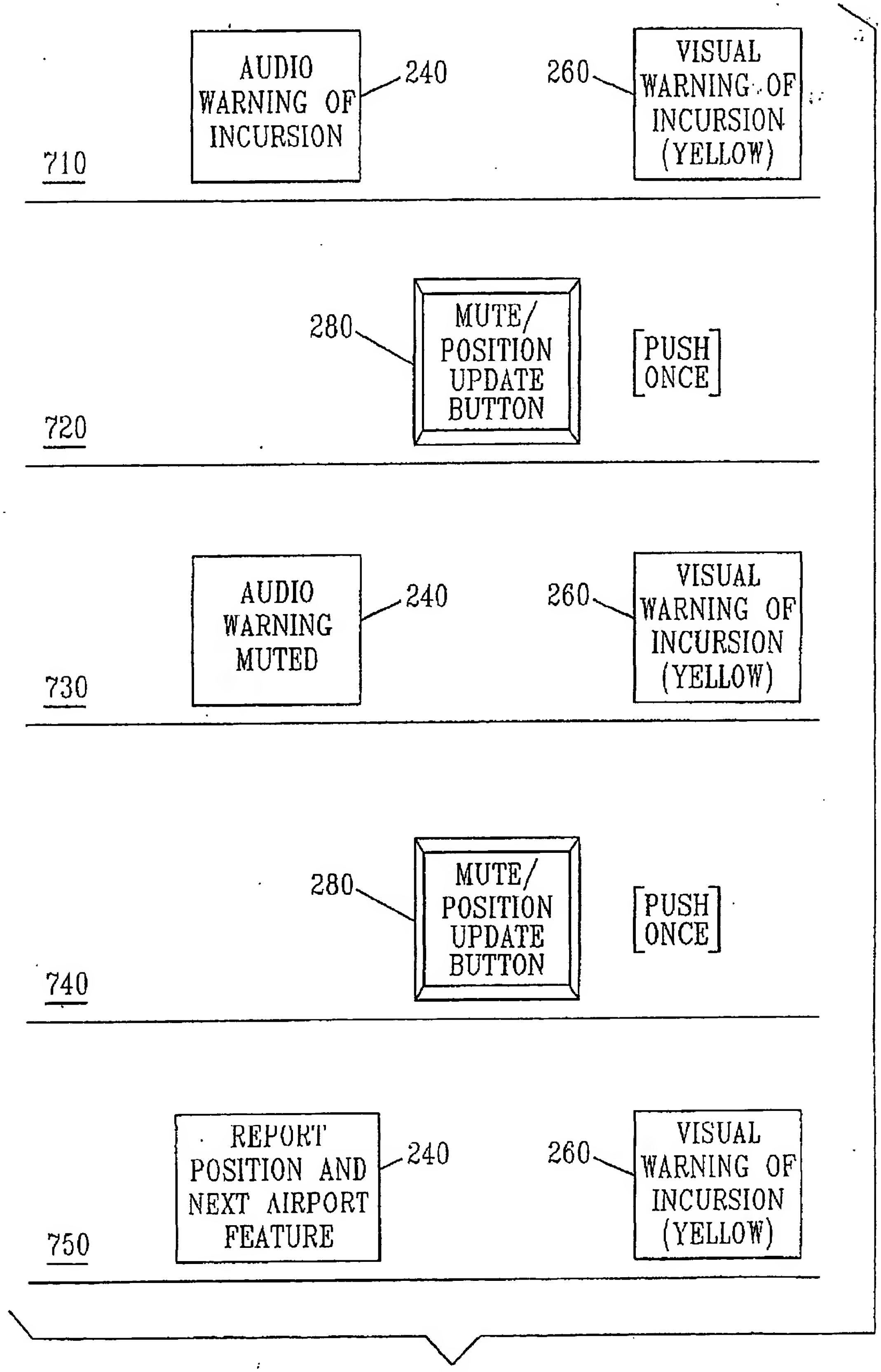
AUDIO WARNING OF INCURSION
240
260
VISUAL WARNING OF INCURSION (YELLOW)
710
280
MUTE/ POSITION UPDATE BUTTON
[PUSH ONCE]
720
AUDIO WARNING MUTED
240
260
VISUAL WARNING OF INCURSION (YELLOW)
730
280
MUTE/ POSITION UPDATE BUTTON
[PUSH ONCE]
740
REPORT POSITION AND NEXT AIRPORT FEATURE
240
260
VISUAL WARNING OF INCURSION (YELLOW)
750

FIG.7